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(54) Method of minimising nitrous oxide emissions in a combustor

Verfahren zur Minimierung von Stickoxiden bei Brennkammer

Procédé de minimisation des oxydes d'azote dans une chambre de combustion

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Description

[0001] The present invention relates to gas turbine engines and, more particularly, to minimization of nitrous oxide emissions without causing combustor instability or a blowout therein.

[0002] As a byproduct of combustion, gas turbine engines typically emit nitrous oxides (NO_x) that are harmful to the atmosphere. Formation of nitrous oxides during the combustion process generally results from a reaction between fuel and air at high temperatures. The level of nitrous oxide emissions can be reduced by controlling the flame temperature during the combustion process. A known approach to controlling the combustion temperature, and therefore to minimizing the nitrous oxide emissions, is to uniformly premix fuel and air prior to combustion to eliminate regions of fuel-rich mixtures which produce locally high combustion temperatures. Once the fuel is uniformly premixed, it is desirable to operate gas turbine engines within a narrow fuel-lean region below a certain combustion temperature to achieve an acceptably low level of nitrous oxide emissions. However, the combustor must operate above a lean blowout temperature to prevent combustion instability and/or a lean blowout.

[0003] The lowest levels of nitrous oxide emissions are attained when gas turbine engines operate as closely as possible to a lean blowout line. However, when the gas turbine engine already operates under fuel-lean conditions and the engine power is reduced, thereby resulting in reduction of fuel flow and in lower flame temperature, the gas turbine engine combustor enters the region of instability and subsequently crosses the line of lean blowout. When the gas turbine engine operates within the instability region, the flames can move upstream and damage the nozzle. If the engine crosses the lean blowout line, the combustion process ceases. Thus, it is desirable to operate gas turbine engines as close as possible to the lean blowout line without crossing the lean blowout line and without operating within the instability zone for a prolonged period of time.

[0004] Presently, the industry is struggling to achieve the lowest possible nitrous oxide emissions without sacrificing safety, durability, and performance of gas turbine engines.

[0005] The present invention seeks to minimize nitrous oxide emissions in gas turbine engines by operating the engine in the most fuel-lean environment possible without causing combustor instability or lean blowout.

[0006] US 54 28 951 relates to controlling combustion devices and teaches the use of a flame kernal pulse actuator to actively control unstable combustion.

[0007] According to the present invention, there is provided in broad terms a method of minimizing nitrous oxide emissions by operating the combustor close to a lean blowout condition which includes a step of monitoring pressure fluctuations within the combustor and a step of adjusting fuel flow entering the combustor to stabilize the combustor in the event that the fluctuations exceed a predetermined threshold.

[0008] The onset of the combustor instability and lean blowout can be detected prior to its occurrence through monitoring of pressure fluctuations within the combustor and subsequent analysis of the pressure fluctuations by a signal analysing means. Once the onset of the blowout is detected, a signal is sent to a fuel schedule controller to adjust fuel flow entering the combustor. The adjustment of fuel may include either an increase in the amount of pilot fuel or control of stages of main fuel or pilot fuel to locally increase the combustion temperature within the combustor. An increased amount of pilot fuel flows into the combustor to increase flame temperature therein and to stabilize combustion. The stages of either main fuel or pilot fuel can be also controlled by reducing the amount of fuel flow to some nozzles and increasing fuel flow to other nozzles. Such staging would result in enriched fuel-lean pockets around the nozzles with increased amount of fuel flow, thereby sustaining the combustion process and minimizing the risk of a lean blowout. Once the analysing means determines that the combustor is stabilized, the fuel flow is adjusted again to return the combustor to fuel-lean combustion. Thus, the present invention allows operation of the combustor very close to the lean blowout line resulting in the lowest levels of nitrous oxide emissions without causing combustor instabilities or lean blowout.

[0009] After corrective action is taken to avert combustor instabilities and/or lean blowout, the combustor returns to fuel-lean operation resulting in low levels of nitrous oxide emissions. Thus, the combustor operates at the enriched fuel-lean level only long enough to stabilize the combustor.

[0010] A preferred embodiment of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a cross section of a gas turbine engine combustor and includes a schematic diagram of an active fuel control system to minimize nitrous oxide emissions;

Figure 2 is a graph of a flame temperature for a given equivalence ratio within the combustor of Figure 1;

Figure 3 is a graph of fuel flow through the main fuel nozzle entering the combustor of Figure 1 at a given time;

Figure 4 is a plot of pressure fluctuations as a function of time as the fuel flow through the main nozzle is varied according to Figure 3;

Figure 5 is a plot of amplitude of pressure fluctuation at frequencies less than three-hundred Hertz (300 Hz) as the fuel flow through the main fuel nozzle is varied according to Figure 3;

Figure 6 is a plot of amplitude of energy associated with dominant combustor frequencies less than

three-hundred Hertz (300 Hz) varying with fuel flowing to the combustor according to Figure 3;

Figure 7 is a plot of the dominant frequency within the combustor of approximately two hundred to two hundred and fifty Hertz (200 - 250 Hz) varying with changes in fuel flow according to Figure 3; and

Figure 8 is a plot of amplitude of a damping coefficient of approximately two hundred to three hundred and fifty (200 - 350 Hz) varying with changes in fuel flow according to Figure 3.

[0011] Referring to Figure 1, an annular combustor 10 is disposed within an annulus 12 between an inner engine case 14 and an outer engine case 16. A diffuser 18 leads axially into the annulus 12 from a compression section (not shown). Each combustor discharges to a turbine section (not shown). A plurality of main fuel nozzles 20 are spaced circumferentially within the annulus 12 to premix the main fuel with a portion of the air exiting the diffuser and to supply the fuel and air mixture to the combustor 10. A plurality of main fuel supply means 22 supply fuel to the main nozzles 20. A plurality of pilot fuel nozzles 26 supply pilot fuel to the combustor 10 with a plurality of pilot fuel supply means 28 distributing fuel to the pilot fuel nozzles 26. A plurality of igniter means (not shown) is disposed within the vicinity of the pilot fuel nozzles 26 to ignite fuel supplied to the pilot fuel nozzles 26.

[0012] A high response pressure probe 30 is disposed within the combustor 10 to monitor pressure fluctuations therein. The pressure probe 30 sends the pressure signal for an on-line signal analysis to a signal analyzing means 32. The signal analyzing means 32 communicates with the fuel schedule controller 34 that adjusts pilot fuel and main fuel flowrates to the combustor 10.

[0013] Referring to Figure 2, a plot of calculated flame temperature for a given equivalence ratio with X axis representing an equivalence ratio and Y axis representing flame temperatures within the combustor is depicted. The equivalence ratio is a ratio of two ratios, with the denominator being equal to the stoichiometric fuel to air ratio for a given fuel and the numerator being equal to an actual fuel to air ratio within the combustor, and can be expressed as:

$$\text{Equivalence Ratio} = \frac{Fuel / Air}{(Fuel / Air)_{\text{Stoichiometric}}}$$

Thus, the plot of Figure 2 represents a graph of flame temperatures associated with burning fuel as a function of fuel/air ratio. It is desirable to operate the combustor in a fuel-lean zone A to obtain low nitrous oxide emissions. To obtain the lowest nitrous oxide emissions, the combustor must be operated as close as possible to a lean blowout line 40. However, as the power of the gas turbine engine is reduced, thus resulting in a reduced amount of fuel flow to the combustor and subsequently lower temperatures, the combustor may enter an instability zone B, that precedes the lean blowout line 40. During the operation of the gas turbine engine, the pressure probe continuously samples the pressure fluctuations within the combustor to detect changes in pressure signal as the combustor enters the instability zone. The analyzing means analyze the pressure signal in a variety of ways. One criteria for analysis of the pressure signal is the magnitude of pressure fluctuation. Figure 3 shows a plot of fuel flow to a combustor during a test, with Y axis representing amount of fuel flow and X axis representing time.

[0014] Referring to Figure 3, amount of fuel flowing to the combustor through a main fuel nozzle is varied during a test. The combustor is initially operating within fuel-lean zone A of Figure 2. The amount of fuel to the combustor is at substantially the same level for the first four seconds (4 sec). The amount of fuel is then continuously reduced starting at four (4) seconds. As the combustor enters the instability zone pressure fluctuations increase until a lean blowout is experienced at approximately nineteen seconds (19 sec).

[0015] Referring to Figure 4, the magnitude of pressure fluctuations varies with the amount of fuel flow to the combustor shown in Figure 3. The magnitude of the pressure signal remains substantially constant at approximately twenty pounds per square inch (20 psi) from zero seconds to approximately four seconds (0 - 4 sec) when the fuel flow to the combustor remains at substantially the same level. The magnitude of the pressure signal begins to grow from approximately 137.9 kPa (20 psi) or 275.8 kPa (40 (psi) peak to peak at four (4) seconds to approximately 344.7 kPa (50 psi) at approximately eighteen (18) seconds, just prior to a lean blowout at approximately nineteen (19) seconds. The threshold for the magnitude signal can be set at approximately 206.8 kPa (30 psi). Thus, if the pressure magnitude signal exceeds 206.8 kPa (30 psi), the analyzing means 32 sends a signal to the fuel schedule controller 34 to adjust fuel flow to the combustor to locally enrich the combustor.

[0016] The present invention identifies an onset of combustor instabilities and/or lean blowout prior to occurrence thereof during operation of the gas turbine engine. A threshold is established to allow sufficient time for corrective action. As the pressure probe 30 continuously sampling the combustor pressure fluctuations, the analyzing means compares the combustor pressure to the previously established threshold. Once the combustion pressure exceeds the threshold, the analyzing means communicates with the fuel schedule controller to adjust the fuel flow to the combustor. Thus, the present invention allows early detection of the upcoming blowout.

[0017] The pressure fluctuations can be analyzed using various criteria. The magnitude of pressure fluctuations less than three hundred Hertz (300 Hz) is another criteria for analyzing the pressure signal. A plot of mag-

nitude of pressure fluctuations (Y axis) as a function of time (X axis) is shown in Figure 5. The magnitude of pressure fluctuations varies as the amount of fuel flow to the combustor is varied according to schedule of Figure 3. The magnitude of pressure fluctuations remains substantially constant from zero seconds to approximately four seconds (0 - 4 sec) at approximately 20.7 kPa (3 psi) when the fuel flow to the combustor is at substantially the same level. The magnitude of the pressure signal begins to grow at approximately four (4) seconds from approximately 20.7 kPa (3 psi) to approximately 68.9 kPa (10 psi) at approximately nineteen (19) seconds, just prior to entering the lean blowout region. A threshold of approximately 34.5 kPa (5 psi) is used to determine the instability. As the magnitude of pressure fluctuations below three hundred Hertz (300 Hz) exceeds the threshold of 34.5 kPa (5 psi) occurring at approximately eleven (11) seconds, the analysing means 32 sends a signal to the fuel schedule controller 34 to adjust fuel flow to the combustor.

[0018] A third criteria for analysing the pressure signal is monitoring energy associated with dominant combustion frequencies below approximately three hundred Hertz (300 Hz). Referring to Figure 6, a plot of magnitude of the fluctuation of a dominant frequency (Y axis) versus time (X axis) shows growth in the magnitude of disturbance after four (4) seconds from approximately 6.9 kPa (1 psi) to 34.5 kPa (5 psi) at approximately eleven (11) seconds. The disturbance subsides after approximately twenty-one (21) seconds after the combustion process ceases. A threshold of 34.5 kPa (5 psi) absolute (or 68.9 kPa (10 psi) peak to peak) is established. When the magnitude of disturbance exceeds the threshold, the analysing means sends a signal to the fuel schedule controller to increase amount of fuel.

[0019] A fourth criteria used to analyze the pressure signal is to monitor the magnitude of the dominant pressure fluctuation frequency within the combustor (Y axis) versus time (X axis), as shown in Figure 7. During the initial four (4) seconds, the dominant frequency is approximately two hundred thirty Hertz (230 Hz). As the amount of fuel into the combustor is decreased, the dominant frequency decreases. The threshold value for this parameter is approximately two hundred Hertz (200 Hz). Thus, if the analysing means 32 senses that the dominant frequency drops below the two hundred Hertz (200 Hz) level, the signal is sent to the fuel schedule controller 34 to adjust fuel flow to the combustor. From this it will be seen that the term "exceeds" as used in this specification may mean to exceed in a positive or negative sense, as appropriate.

[0020] The fifth criteria to analyze pressure signals is to monitor a damping coefficient associated with the pressure fluctuations. Referring to Figure 8, a magnitude of damping coefficient (Y axis) versus time (X axis) plot reveals that the magnitude of the damping coefficient decreases after approximately four (4) seconds as the combustor approaches instability at approximately nineteen (19) seconds. Thus, if the analysing means 32 senses that the damping coefficient becomes less than zero (0), it sends a signal to the fuel schedule controller 34 to adjust fuel flow to the combustor to avoid lean blowout. The damping coefficient may be regarded as representing an inverse of the magnitude of the pressure fluctuations, as decreased damping would allow the magnitude of the fluctuations to increase.

[0021] Although any one of the five methods to analyze the pressure signal establishes a precursor condition, a combination of methods can be used to insure a more accurate system. If the analysing means 32 senses that at least two of the parameters have crossed the threshold limit, then it will communicate with the fuel schedule controller 34. The analysing means 32 can be set up to be triggered by as few as one parameter or as many as all five.

[0022] As soon as the fuel schedule controller 34 receives a signal from the analyzing means 32 to adjust fuel flow to the combustor, fuel flow can be adjusted by either increasing fuel flow through the pilot fuel nozzles or staging main fuel nozzles and/or pilot fuel nozzles. If the fuel output through the pilot fuel nozzle is increased, the combustion process increases at those discrete locations around the pilot fuel nozzles with greater amounts of fuel and higher flame temperatures. Although the level of nitrous oxide emission increases with increased level of fuel, the combustor avoids entering the lean blowout zone. The lean blowout also can be avoided by staging either the main fuel nozzles or the pilot fuel nozzles. The fuel flow to some of the nozzles is cut off and redistributed to a lesser number of nozzles. Thus, the fuel flow to some number of fuel nozzles is increased, resulting in enriched burning in those discrete locations, thereby sustaining combustion within the combustor.

[0023] Once the combustor pressure indicators move within the threshold limits, the amount of fuel can be reduced so that the leanest possible combustion process is maintained within the combustor.

[0024] One primary advantage of the present invention is that low levels of nitrous oxides are maintained without the combustor blowing out or entering the instability zone for a prolonged period of time. The lowest levels of nitrous oxides are achieved when the combustor operates in the fuel-lean environment, zone A, in Figure 2, as close to the lean blowout line 40 as possible. However, prior to the combustor crossing the lean blowout line, the combustor operates within instability zone B. Since it is highly undesirable to either cross the lean blowout line or operate within the instability zone for a prolonged period of time, the present invention establishes precursor conditions to either one of the events and allows preventive measures to be taken to avert a low lean blowout or an instability, while achieving low NO_x. The present invention further allows the combustor to operate at the lowest levels of NO_x emissions after the combustor operation stabilizes.

[0025] The analyzing means can be any type of computing device with a number of software packages. One commercially available software product that is suitable for the present application is MATLAB®, a registered trademark of the Math Works, Inc. of Natick, Massachusetts.

[0026] The pressure probe 30 shown in Figure 1 can be disposed at a variety of locations. The pressure probe 30 can be disposed either within the combustor or in the vicinity of the combustor. The threshold for the pressure signal parameters disclosed above, with the exception of the frequency parameter, vary depending on the location of the pressure probe 30. Also, the threshold values can be adjusted to allow sufficient amount of time for corrective action to be taken.

[0027] Although the invention has been shown and described with respect to preferred embodiments thereof, it should be understood by those skilled in the art that various changes and omissions in the form and detail thereof may be made therein without departing from the scope of the invention as defined by the following claims.

Claims

1. A method of minimizing nitrous oxide emissions in a combustor, said method comprising:

   operating the combustor close to a lean blowout condition;
   monitoring pressure fluctuations within said combustor; and
   adjusting the fuel flow to said combustor when said pressure fluctuations within said combustor exceed a predetermined threshold.

2. The method as claimed in claim 1 wherein the amount of fuel flow with respect to air flow to at least a portion of said combustor is increased when said pressure fluctuations within said combustor exceed a predetermined threshold.

3. The method according to claim 1 or 2, comprising the step of comparing the magnitude of said pressure fluctuations with a previously established said threshold.

4. The method according to claim 1, 2 or 3, comprising the step of comparing the magnitude of pressure fluctuations less than three hundred Hertz (300 Hz) with said threshold.

5. The method according to any preceding claim comprising the step of comparing energy associated with dominant combustion frequencies below approximately three hundred Hertz (300 Hz) with said threshold.

6. The method according to any preceding claim comprising the step of comparing the magnitude of a dominant pressure fluctuation frequency within said combustor with said threshold.

7. The method according to any preceding claim comprising the step of comparing the magnitude of a damping coefficient derived from said pressure fluctuations with said threshold.

8. The method according to any preceding claim comprising the step of sending a signal to fuel schedule control means to adjust the amount of fuel supplied to said combustor.

9. The method according to claim 8, comprising a subsequent step of increasing the amount of fuel to pilot fuel nozzles within the combustor.

10. The method according to any preceding claim, wherein a plurality of pilot fuel nozzles is staged so that fuel flow to some of said plurality of pilot fuel nozzles is decreased and fuel flow to other said pilot nozzles is increased to result in a zone of enriched fuel-lean combustion within said combustor.

11. The method according to any of claims 1 to 9, wherein a plurality of main fuel nozzles is staged so that fuel flow to some of said plurality of main fuel nozzles is decreased and fuel flow to other said main nozzles is increased to result in a zone of enriched fuel-lean combustion within said combustor.

12. The method according to any preceding claim comprising the subsequent steps of:

    continuing to monitor said pressure fluctuations; and
    adjusting the amount of fuel supplied to said combustor when said pressure fluctuations fall below said threshold to maintain fuel-lean combustion within said combustor.

13. The method as claimed in claim 1 said method comprising:

    monitoring pressure fluctuations within said combustor continuously throughout a combustion process within said combustor;
    analysing said pressure fluctuations;
    sending a first signal to fuel schedule controller means once said pressure fluctuations exceed a preestablished threshold;
    adjusting fuel flow into said combustor to avoid combustion instability and lean blowout;
    continuing to monitor said pressure fluctuations;
    sending said a second signal to said fuel sched-

ule controller means once said pressure fluctuations fall below said preestablished threshold; and
readjusting fuel flow to operate said combustor in fuel-lean environment.

Patentansprüche

1. Verfahren zum Minimieren von Stickoxidemissionen in einer Brennkammereinrichtung, wobei das Verfahren aufweist:

   Betreiben der Brennkammereinrichtung nahe bei einem Zustand für Mager-Verlöschen;
   Überwachen von Druckfluktuationen in der Brennkammereinrichtung; und
   Einstellen der Brennstoffströmung zu der Brennkammereinrichtung, wenn die Druckfluktuationen in der Brennkammereinrichtung eine vorbestimmte Schwelle überschreiten.

2. Verfahren nach Anspruch 1, wobei die Mange an Brennstoffströmung bezogen auf die Luftströmung zu mindestens einem Teil der Brennkammereinrichtung erhöht wird, wenn die Druckschwankungen in der Brennkammereinrichtung eine vorbestimmte Schwelle überschreiten.

3. Verfahren nach Anspruch 1 oder 2, aufweisend den Schritt des Vergleichens der Größe der Druckschwankungen mit einer vorher etablierten Schwelle.

4. Verfahren nach Anspruch 1, 2 oder 3, aufweisend den Schritt des Vergleichens der Größe der Druckschwankungen unterhalb dreihundert Hertz (300 Hz) mit der Schwelle.

5. Verfahren nach einem der vorangehenden Ansprüche, aufweisend den Schritt des Vergleichens der Energie, die zu dominanten Verbrennungsfrequenzen unterhalb etwa dreihundert Hertz (300 Hz) gehört, mit der Schwelle.

6. Verfahren nach einem der vorangehenden Ansprüche, aufweisend den Schritt des Vergleichens der Größe einer dominanten Druckschwankungsfrequenz in der Brennkammereinrichtung mit der Schwelle.

7. Verfahren nach einem der vorangehenden Ansprüche, aufweisend den Schritt des Vergleichens der Größe eines Dämpfungskoeffizienten, der aus den Druckschwankungen abgeleitet wurde, mit der Schwelle.

8. Verfahren nach einem der vorangehenden Ansprüche, aufweisend den Schritt des Sendens eines Signals an eine Brennstoffbedarfssteuerung, um die Menge an Brennstoff, die der Brennkammereinrichtung zugeführt wird, einzustellen.

9. Verfahren nach Anspruch 8, aufweisend einen anschließenden Schritt des Erhöhens der Menge an Brennstoff zu Pilot-Brennstoffdüsen in der Brennkammereinrichtung.

10. Verfahren nach einem der vorangehenden Ansprüche, wobei eine Mehrzahl von Pilot-Brennstoffdüsen gestuft wird, so dass Brennstoffströmung zu manchen aus der Mehrzahl von Pilot-Brennstoffdüsen verringert wird und Brennstoffströmung zu anderen der Pilot-Brennstoffdüsen erhöht wird, um im Ergebnis eine Zone von angereicherter brennstoffmagerer Verbrennung in der Brennkammereinrichtung zu haben.

11. Verfahren nach einem der Ansprüche 1 bis 9, wobei eine Mehrzahl von Haupt-Brennstoffdüsen gestuft wird, so dass die Brennstoffströmung zu manchen aus der Mehrzahl von Haupt-Brennstoffdüsen verringert wird und die Brennstoffströmung zu anderen der Haupt-Brennstoffdüsen erhöht wird, um im Ergebnis eine Zone von angereicherter brennstoffmagerer Verbrennung in der Brennkammereinrichtung zu haben.

12. Verfahren nach einem der vorangehenden Ansprüche, aufweisend die nachfolgenden Schritte:

    Fortsetzen der Überwachung der Druckschwankungen; und
    Einstellen der der Brennkammereinrichtung gelieferten Menge an Brennstoff, wenn die Druckschwankungen unter die Schwelle fallen, um eine brennstoffmagere Verbrennung in der Brennkammereinrichtung beizubehalten.

13. Verfahren nach Anspruch 1, wobei das Verfahren aufweist:

    Überwachen der Druckschwankungen in der Brennkammereinrichtung kontinuierlich über einen Verbrennungsprozess in der Brennkammereinrichtung;
    Analysieren der Druckschwankungen;
    Senden eines ersten Signals an eine Brennstoffbedarfssteuerung, sobald die Druckschwankungen eine vorher etablierte Schwelle überschreiten;
    Einstellen der Brennstoffströmung in die Brennkammereinrichtung zum Vermeiden einer Verbrennungsinstabilität und Mager-Verlöschens;
    Fortsetzen der Überwachung der Druck-

schwankungen;
Senden eines zweiten Signals an die Brennstoffbedarfssteuerung, sobald die Druckschwankungen unterhalb die vorher etablierte Schwelle fallen; und
Neueinstellen der Brennstoffströmung, um die Brennkammereinrichtung in einer brennstoffmageren Umgebung zu betreiben.

Revendications

1. Procédé de minimisation des émissions d'oxydes nitreux dans une chambre de combustion, ledit procédé comprenant les étapes qui consistent à :

    faire fonctionner la chambre de combustion à proximité de la condition d'extinction par pauvreté du mélange ;
    surveiller les variations de pression dans ladite chambre de combustion ; et
    ajuster le débit du combustible envoyé à ladite chambre de combustion lorsque lesdites variations de pression dans ladite chambre de combustion excèdent une valeur seuil prédéterminée.

2. Procédé selon la revendication 1, dans lequel le rapport de la quantité de combustible à la quantité d'air envoyées à au moins une partie de ladite chambre de combustion est augmenté lorsque lesdites variations de pression dans ladite chambre de combustion excèdent une valeur seuil prédéterminée.

3. Procédé selon la revendication 1 ou 2, comprenant l'étape qui consiste à comparer l'importance desdites variations de pression à ladite valeur seuil préalablement établie.

4. Procédé selon la revendication 1, 2 ou 3, comprenant l'étape qui consiste à comparer l'importance desdites variations de pression inférieures à trois cents hertz (300 Hz) à ladite valeur seuil.

5. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape qui consiste à comparer l'énergie associée aux fréquences de combustion dominantes inférieures à environ trois cents hertz (300 Hz) à ladite valeur seuil.

6. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape qui consiste à comparer la valeur d'une fréquence de variation de pression dominante dans ladite chambre de combustion a ladite valeur seuil.

7. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape qui consiste à comparer la valeur d'un coefficient d'amortissement déduit desdites variations de pression à ladite valeur seuil.

8. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape qui consiste à envoyer un signal à des moyens de régulation du mélange combustible pour ajuster la quantité de combustible qui est envoyée à ladite chambre de combustion.

9. Procédé selon la revendication 8, comprenant une étape ultérieure qui consiste à augmenter la quantité de combustible envoyée aux injecteurs de combustible pilotes à l'intérieur de la chambre de combustion.

10. Procédé selon l'une quelconque des revendications précédentes, dans lequel une pluralité d'injecteurs de combustible pilotes est organisée de façon telle que l'écoulement de combustible vers certains desdits différents injecteurs de combustible pilotes soit réduit et que l'écoulement de combustible vers certains autres desdits injecteurs pilotes soit augmenté, de manière à créer une zone de combustion en mélange pauvre enrichi dans ladite chambre de combustion.

11. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel une pluralité d'injecteurs de combustible principaux est organisée de façon telle que l'écoulement de combustible vers certains desdits différents injecteurs de combustible principaux soit réduit et que l'écoulement de combustible vers certains autres desdits injecteurs principaux soit augmenté, de manière à créer une zone de combustion en mélange pauvre enrichi dans ladite chambre de combustion.

12. Procédé selon l'une quelconque des revendications précédentes, comprenant les étapes ultérieures qui consistent à:

    continuer à surveiller lesdites variations de pression ; et
    ajuster la quantité de combustible qui est envoyée à ladite chambre de combustion lorsque lesdites variations de pression deviennent inférieures à ladite valeur seuil, de manière à maintenir une combustion en mélange pauvre à l'intérieur de ladite chambre de combustion.

13. Procédé selon la revendication 1, ledit procédé comprenant les étapes qui consistent à :

    surveiller les variations de pression dans ladite chambre de combustion, en continu, sur tout un

processus de combustion dans ladite chambre de combustion ;
analyser lesdites variations de pression ;
envoyer un premier signal aux moyens de régulation du mélange combustible lorsque lesdites variations de pression sont devenues supérieures à une valeur seuil prédéterminée ;
ajuster l'écoulement de combustible envoyé dans ladite chambre de combustion de manière à éviter une instabilité de combustion et une extinction par pauvreté du mélange ;
continuer à surveiller lesdites variations de pression ;
envoyer un deuxième signal auxdits moyens de régulation du mélange combustible lorsque lesdites variations de pression sont devenues inférieures à ladite valeur seuil prédéterminée ; et
réajuster l'écoulement du combustible pour faire fonctionner la chambre de combustion dans un environnement de combustion en mélange pauvre.

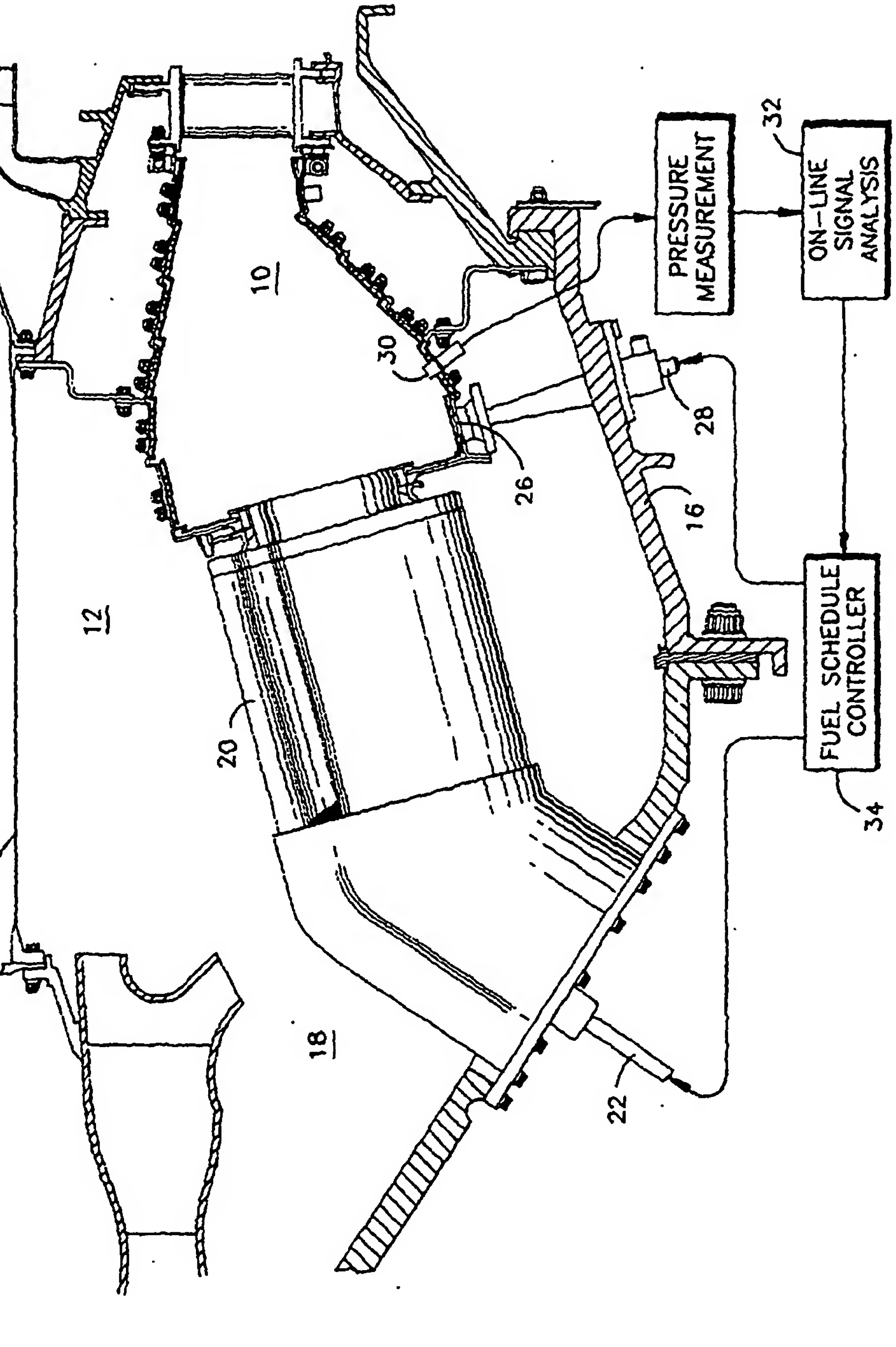

PRESSURE MEASUREMENT
ON-LINE SIGNAL ANALYSIS
FUEL SCHEDULE CONTROLLER
10
12
14
16
18
20
22
26
28
30
32
34

FIG.1

FIG.2

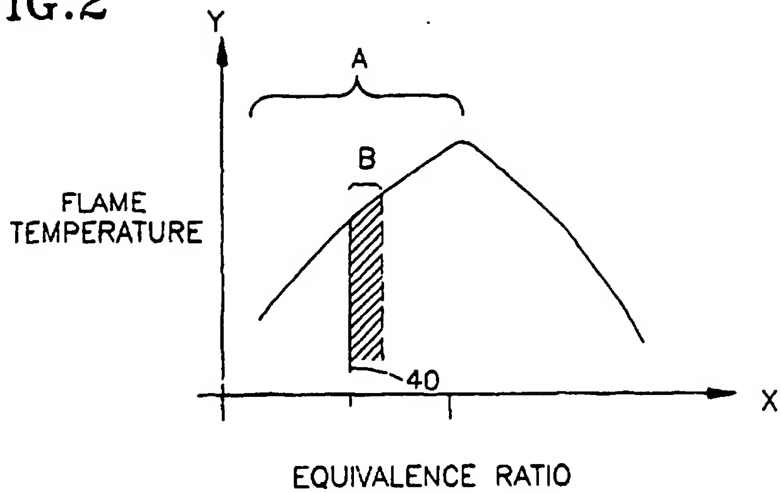

Y
A
B
FLAME TEMPERATURE
40
X
EQUIVALENCE RATIO

FIG.3

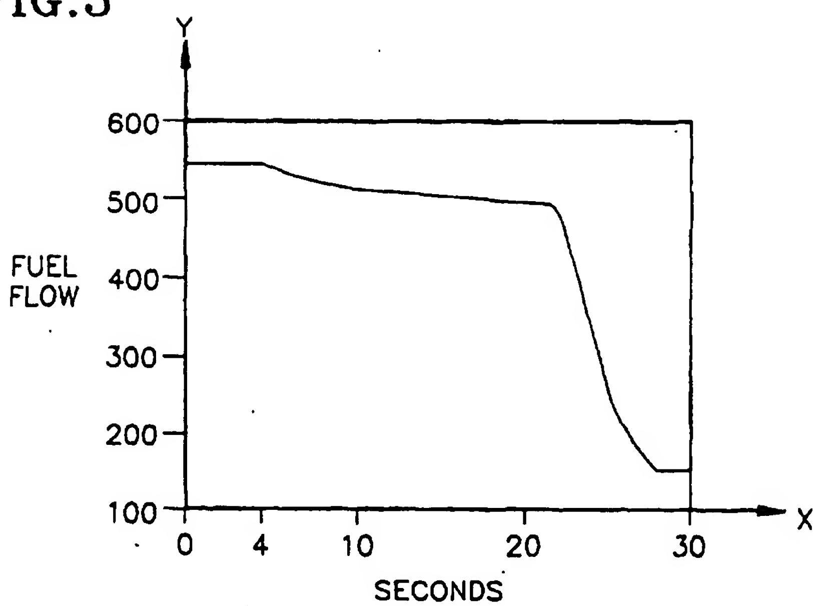

Y
600
500
400
300
200
100
FUEL FLOW
0
4
10
20
30
X
SECONDS

FIG.4

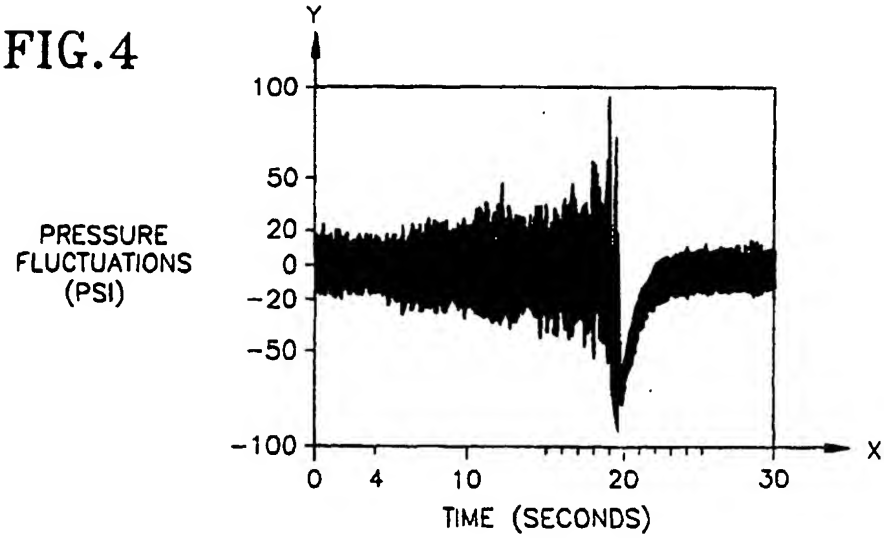
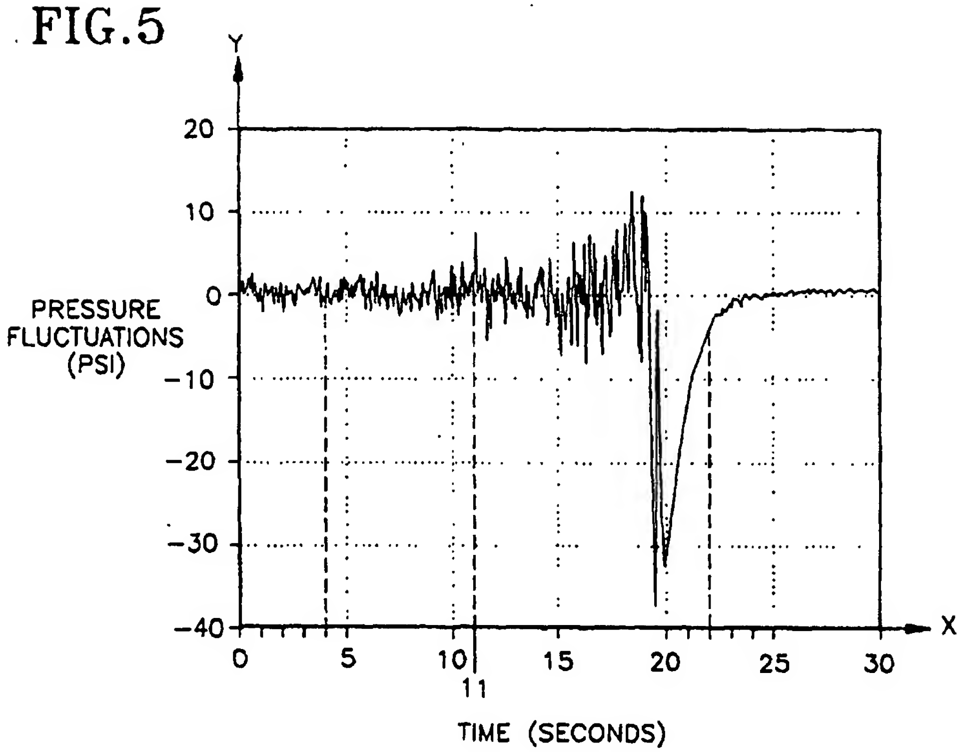

Y
100
50
20
0
-20
-50
-100
PRESSURE
FLUCTUATIONS
(PSI)
0
4
10
20
30
X
TIME (SECONDS)

FIG.5


Y
20
10
0
-10
-20
-30
-40
PRESSURE
FLUCTUATIONS
(PSI)
0
5
10
11
15
20
25
30
X
TIME (SECONDS)

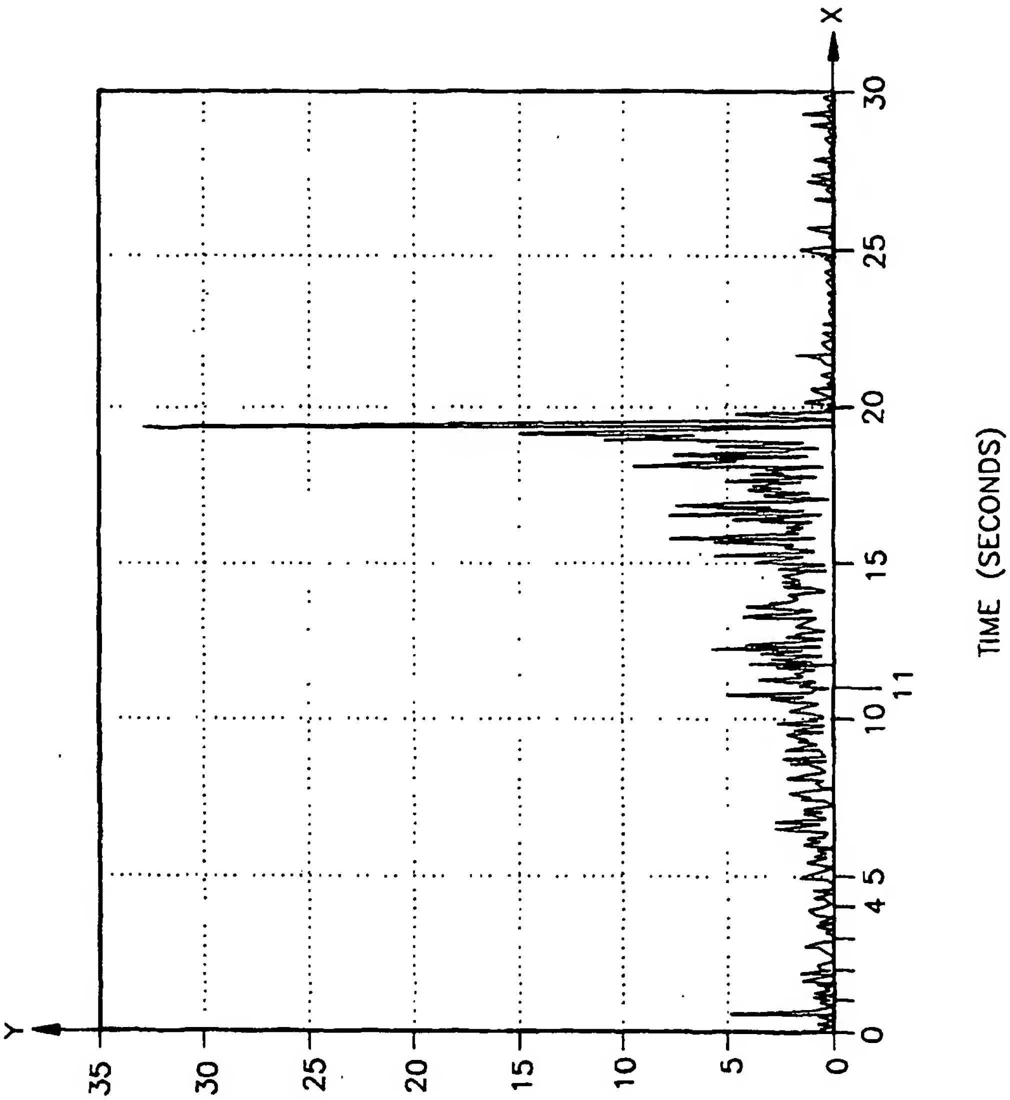

Y
X
35
30
25
20
15
10
5
0
0
4
5
10
11
15
20
25
30
TIME (SECONDS)
AMPLITUDE (PSI)

FIG.6

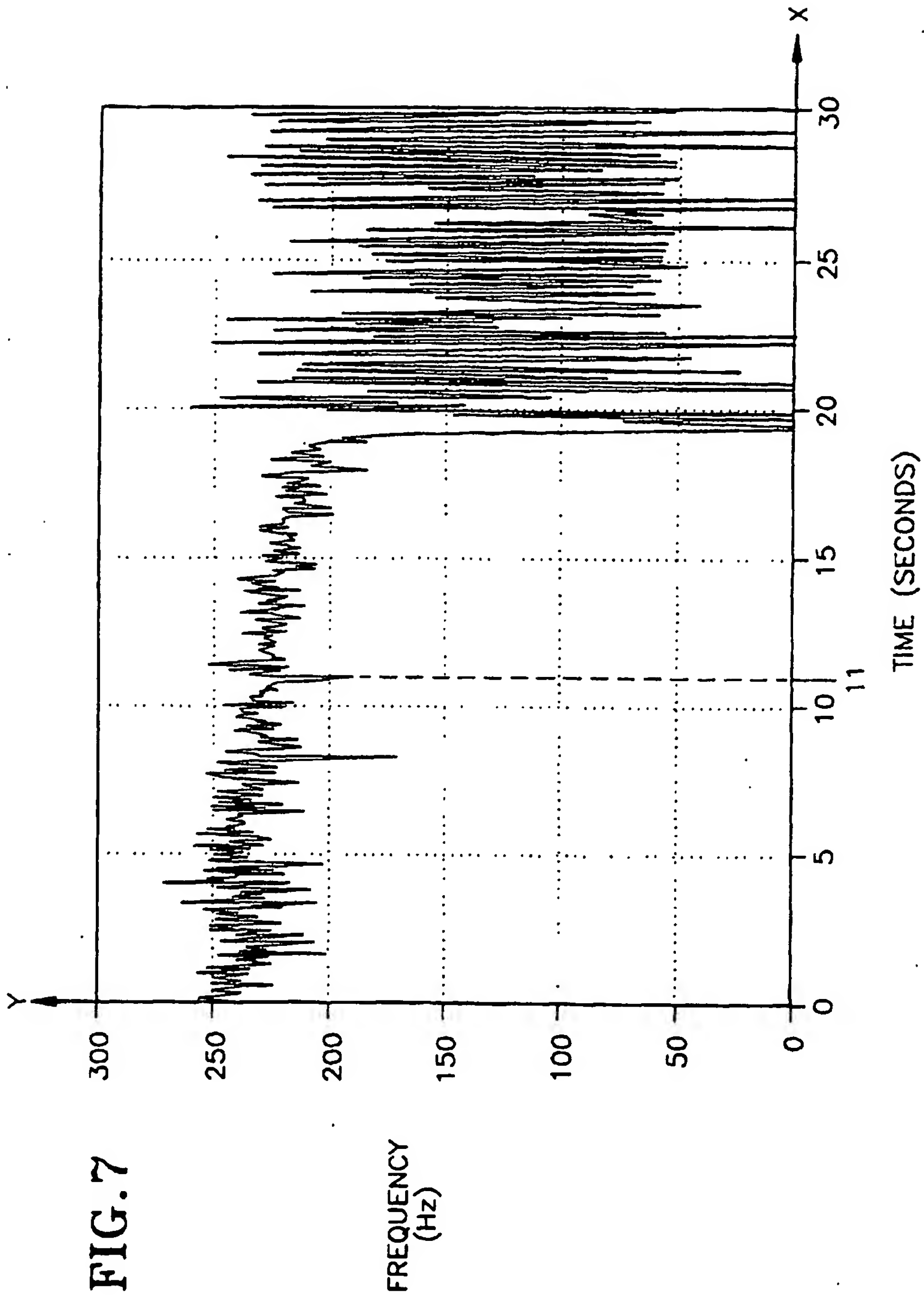
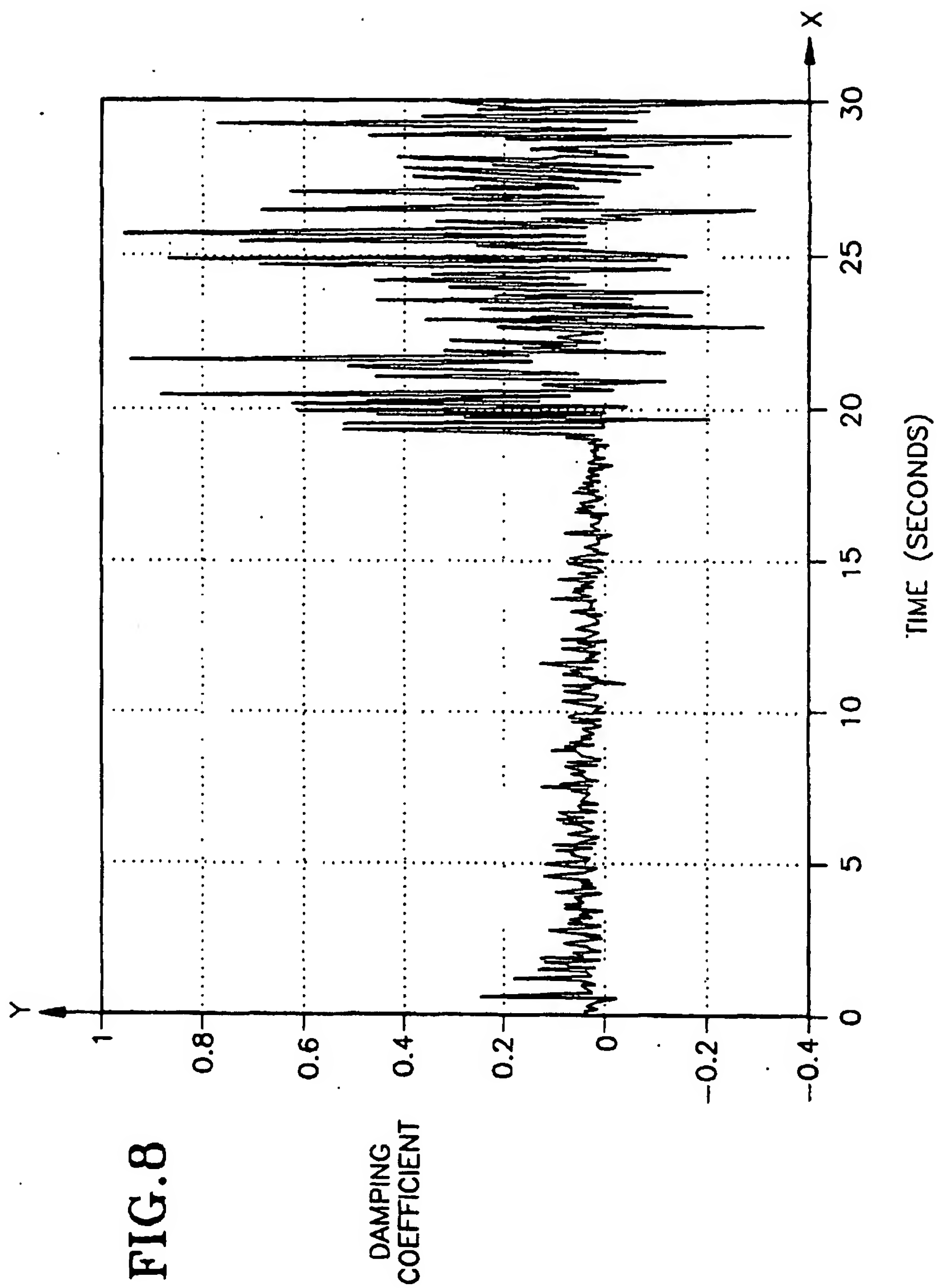

Y
X
300
250
200
150
100
50
0
0
5
10
11
15
20
25
30
TIME (SECONDS)
FREQUENCY
(Hz)

FIG. 7

FIG.8


DAMPING COEFFICIENT
Y
X
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
5
10
15
20
25
30
TIME (SECONDS)